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Synthesis and Characterization of *Gambas* (*Luffa acutangula*) Peel–Based Bioplastic Reinforced by Silica

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Abstract

Gambas (Luffa acutangula) plants contain a relatively high carbohydrate of 68.2%, whereas its peel contains 38.94% of carbohydrates and 20.6% of fibers. Gambas peels are rarely utilized and are typically discarded as food waste. Silica can be used as a filler and reinforcement material to improve the physical and mechanical properties. This study discussed synthesizing and characterizing bioplastics from Gambas peel reinforced by silica using polyvinyl alcohol (PVA) as a plasticizer with a mass of 8 g and 9 g and vinegar as a compatibilizer with volumes of 7 mL and 8 mL. The gelatinization temperature was adjusted at 85°C and 95°C. The synthesized bioplastics have improved mechanical characteristics due to the addition of PVA. The addition of vinegar as a compatibilizer revealed a homogenous mixture in surface morphological analysis. The highest performance of bioplastic samples was obtained from sample 7 with 8 mL vinegar, 9 g of PVA, and at 85°C of gelatinization temperature. The results showed that the maximum tensile strength reached 0.034 N/mm^2, the elongation was 225%, the value of Young's modulus was 0.015 N/mm^2, the thermal stability reached 74.34% weight loss by heating up to 400°C, and the melting temperature reached at 220°C, the absorption of water was 37.61%, and the weight loss was 20.3% after ten days of soil burial.

1. Introduction

According to The World Economic Forum, in 2023, at least 350 million metric tons of plastic are produced annually. According to the Center for International Environmental Law, plastic manufacturing sectors will consume 20% of crude oil by 2050 if plastic use continues to increase. According to World Bank data from 2021, Indonesia produced 7.8 million tons of plastic waste annually, of which 4.9 million tons were released into the environment. Most of the plastic used in daily life still contains non-biodegradable compounds. Conventional plastics can be replaced with bioplastics or biodegradable plastics to reduce plastic waste. Natural polymers, such as polysaccharides, are abundant in nature, including carbohydrates, starch, cellulose, and fibers [1]. Polysaccharides can be used as raw materials for bioplastic production because they are easily degraded, thus replacing petroleum-based plastics [2]. Gambas plants contain a relatively high carbohydrate of 68.2%, whereas gambas peels contain 38.94% of carbohydrates and 20.6% of fibers [3, 4]. Thus, they can be used as raw bioplastic materials. Gambas (*Luffa acutangula*) are found in many Asian countries, especially in Indonesia. Gambas plants belong to the Cucurbitaceae family and are part of the cucumber plants family [5]. Most Indonesians call it oyong. Gambas peel has not been widely used, and when it is disposed only to be food waste. According to Food and Agricultural Organization (FAO) (2023), food waste is estimated to reach 1.3 billion tons. Previous studies have successfully synthesized bioplastic from food and agricultural wastes, especially fruit peel [2, 6, 7].

One of the materials utilized to create bioplastics, polysaccharides, unfortunately, have weak mechanical and physical properties. Therefore, reinforcing materials are required to improve these two properties, such as using silica, one of the most abundant natural materials [8], as a filler and reinforcement material. Silica is a material that is widely utilized to synthesize polymers

and composites due to its great biocompatibility and non-toxicity. Moreover, silica also resists high pressure and temperature conditions [9]. Also, silica can enhance bioplastic thermal stability [10]. The use of silica to reinforce bioplastic was observed, and the result indicated that silica could be employed as a bioplastic reinforcing material and reached tensile strength and elongation of 14.12 MPa and 30.7%, respectively [11]. Another study by Wang *et al.* [12] showed that synthesizing polymer using silica as raw materials can improve mechanical properties, especially tensile strength, by 31.3 MPa. Besides that, bioplastic synthesis also uses plasticizers to adjust flexibility and have plastic characteristics. Adding polyvinyl alcohol (PVA) as a plasticizer can improve plastics and mechanical properties. The study by Jayakumar *et al.* [13] revealed that adding PVA improves mechanical properties, such as maximum tensile strength by 26.18 MPa and elongation by 26.6%. A study by Remiš *et al.* [14] reported that adding PVA also can enhance the tensile strength by 63.3 MPa. Another study by Patil *et al.* [15] showed that pure PVA-based bioplastic films had reached 17.9 MPa of tensile strength and 219.8% of elongation. It implies that PVA can enhance mechanical and flexibility properties. In addition, PVA is non-toxic material with good thermal stability and high biocompatibility. Hence, PVA applies to bioplastic fabrications [16]. However, research on incorporating Gambas peel, PVA, and silica into a material has never been reported. This combination is expected to produce a bioplastic material that is more rigid, stronger, flexible, and thermally stable. In addition, the fiber and carbohydrate contents of the Gambas peel can support the improvement of its physical and mechanical properties.

This study aims to synthesize and characterize bioplastics from Gambas peels reinforced with silica-based filler, polyvinyl alcohol (PVA) as a plasticizer, and vinegar as a solvent and compatibilizer with different gelatinization temperatures. Combining these different components attempts to improve the physical, mechanical, and thermal properties of the resulting bioplastics. Additionally, producing bioplastics from renewable resources is meant to reduce the impact of both conventional plastic and Gambas wastes.

2. Materials and Methods

2.1. Materials

Gambas *(Luffa acutangula)* peels were obtained from the local traditional market, polyvinyl alcohol (95%) for laboratory use was purchased from a local chemicals store in Indonesia, food vinegar (5% acidity) (HEINZ) was purchased from a local store in Indonesia, vegetable glycerin with a pharmaceutical grade of 99.7% (Lansida), silica (SiO_2) powder (96%) were obtained from PT. Infiniti Sumber Alam, Indonesia, distilled water, and soils.

2.2. Pre-treatment

The method was modified from previous studies [2, 6]. The peels of Gambas were washed and sun-dried for a day until they were wilted. Then, the wilted peels were reduced and cut into small pieces. The sample was ground and then sieved using a 12-mesh sieve.

2.3. Synthesis of Bioplastics

The synthesis method was modified from the previous study by Shafqat *et al.* [2]. Ten g of Gambas peels, 5 g of silica powder, polyvinyl alcohol with various weights of 8 g and 9 g, food vinegar with various volumes of 7 mL and 8 mL, 9 g of vegetable glycerin, and 15 mL of distilled water were homogenized and gelatinized by stirring on a hotplate at 120 rpm for approximately 60 minutes. The gelatinization temperature was varied at 85°C and 95°C until molten bioplastics were formed. Then, the molten bioplastics were allowed to stand at room temperature and poured for the casting process on an aluminum foil container, followed drying process in an oven at 85°C for around 2 hours. After the drying process, the samples were cooled down to room temperature.

2.4. Mechanical Tests

Mechanical tests consisted of tensile strength, elasticity modulus, and elongation tests. The tests were modified from the ASTM D882 test standard. The tensile strength test used a Computer Control Electronical Universal Testing Machine model of WDW-5 with a load of 5 kN and 220 V/50 Hz power at the Chemical Engineering Laboratory, Universitas Muhammadiyah Surakarta. The speed was adjusted at 10 mm/min. The dimensions of the samples were 80 mm in length, 20 mm in width, and 1.5 mm in thickness.

2.5. Functional Group Analysis

Functional groups of bioplastic samples were identified using Fourier Transform Infra-Red (Shimadzu, Japan) at the Integrated Laboratory, Faculty of Mathematics and Natural Sciences, Sebelas Maret University.

2.6. Morphological Analysis

The surface morphology of bioplastic samples was analyzed by Scanning Electron Microscopy (Quanta 250) at the Integrated Laboratory, Faculty of Mathematics and Natural Sciences, Sebelas Maret University.

2.7. Thermal Stability Analysis

Thermal analysis for bioplastics was performed using thermogravimetry differential thermal analysis (TG/DTA) (Shimadzu DTG-60, Japan) at the University Center of Excellence for Electrical Energy Storage Technology, Sebelas Maret University. Samples (3.5 to 7.5 mg) were analyzed using TG/DTA to determine weight loss and thermal stability. Samples were heated simultaneously from room temperature to 400°C with a heat rate of 5°C/min.

2.8. Soil Degradation Analysis

An analysis of soil degradation involves burying soil samples to determine their biodegradability characteristics. The procedure was modified from a previous study [2]. Samples were cut into 2 cm × 2 cm and then weighed to measure the initial weight (W_0). Samples were then buried in garden soil for five and ten days at a depth of 2 cm inside an aluminum foil container. After five and ten days, the samples were washed and weighed for

final weight (W_1). The biodegradability of the sample was calculated using Equation (1).

$$Biodegradability = \frac{w_0 - w_1}{w_0} \quad (1)$$

2.9. Water Absorption Test

The water absorption test was modified from a previous study [17]. Samples were cut into 2 cm × 2 cm and weighed to measure the initial weight (W_0). Then, samples were immersed in 20 mL of distilled water for 10 minutes at room temperature. After 10 minutes, the samples were removed from distilled water to measure the final weight (W_1). The amount of absorbed water was calculated using Equation (2).

$$Absorption\ of\ water = \frac{w_1 - w_0}{w_0} \times 100\% \quad (2)$$

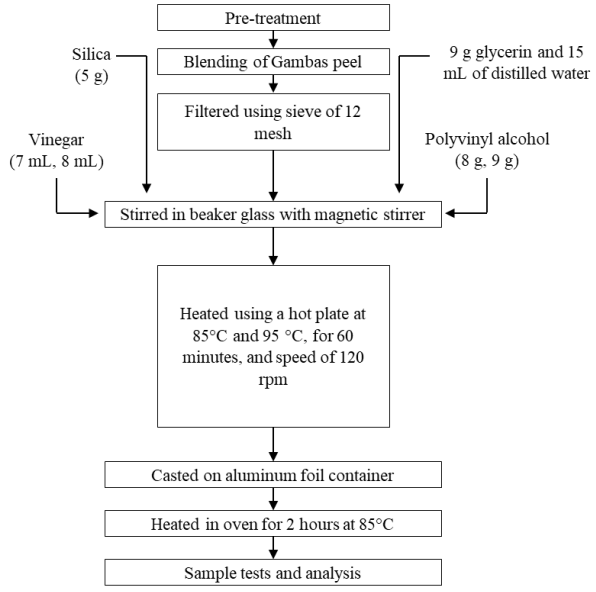

Figure 1. Diagram flow of the research

2.10. Experimental Design

Table 1 represents the experimental design of samples. The variables included food vinegar, PVA, and gelatinization temperature have been observed to analyze their effects on characteristics of resulted bioplastics.

Table 1. Experimental design of samples

Sample	Gambas peel (g)	Silica (g)	Food Vinegar (mL)	PVA (g)	Gelatinization temperature (°C)
1	10	5	7	8	85
2	10	5	7	8	95
3	10	5	7	9	85
4	10	5	7	9	95
5	10	5	8	8	85
6	10	5	8	8	95
7	10	5	8	9	85
8	10	5	8	9	95

3. Results and Discussion

3.1. Mechanical Analysis

The results of the mechanical analysis can be seen in Table 2. The increase in gelatinization temperature from sample 1 to sample 2 causes an increase in tensile strength. This also applies to the results from sample 3 to sample 4, which experienced increased tensile strength. The increase in gelatinization temperature can be caused by an even and completely soluble distribution of carbohydrate molecules, thereby increasing intermolecular bonds between ingredients. These bonds cause the resulting bioplastics to become more rigid and tough [18]. On the contrary, the contrast phenomenon occurred on sample 5 to sample 6 and sample 7 to sample 8. Alonso-González *et al.* [19], a study investigating the effect of mixing temperature on the synthesis of starch bioplastics, reported that increasing the mixing temperature led to an increase in Young's modulus and tensile strength, as well as a decrease in elongation at break, with the best results being at 80–90°C. Young's modulus and elongation values may have increased due to cross-linkage chains forming, which increase toughness and flexibility. For instance, the study by Balaguer *et al.* [20] revealed that the increase in mixing temperature could improve mechanical properties such as elongation, tensile strength, and Young's modulus in line with the toughness and flexibility of bioplastic samples. Regarding the elongation, the increase in gelatinization temperature had similar results with tensile strength tendencies, whereas the increase in gelatinization temperature from sample 1 to sample 2 caused the increase in elongation.

Table 2. Mechanical properties of samples

Sample	Food vinegar (mL)	PVA (g)	Gelatinization temperature (°C)	Tensile strength (N/mm^2)	% Elongation	Young's modulus (E) (N/mm^2)
1	7	8	85	0.002	28	0.0071
2	7	8	95	0.009	72	0.0125
3	7	9	85	0.005	142	0.0035
4	7	9	95	0.015	175	0.0086
5	8	8	85	0.027	126	0.0214
6	8	8	95	0.014	87.5	0.016
7	8	9	85	0.034	225	0.015
8	8	9	95	0.008	121.3	0.0066

The same result demonstrates that samples 3 to 4 experienced increased elongation when the gelatinization temperature was increased. In contrast, samples 5 to 6 and 7 to 8 showed decreased elongation and Young's modulus when the temperature was increased to 95°C. The elongation value decreased as the gelatinization temperature rose, presumably due to changes to the structure of starch or polysaccharides brought on by heating while mixing the materials. Zakaria *et al.* [21] showed that increasing the mixing temperature resulted in a more fragile starch film and lower elongation at break. In addition, plasticizers and compatibilizers, as other variables, also affect the mechanical properties. This study achieved the maximum values by sample 7 with tensile strength, elongation, and Young's modulus of 0.034 N/mm^2, 225%, and 0.015 N/mm^2, respectively.

Increasing the volume of vinegar causes an increase in tensile strength from sample 4 to sample 5. However, there is a decrease in the tensile strength value from samples 7 to 8. Previous studies reported that the

maximum tensile strength of 5 N/mm² was obtained with 8% vinegar of the total volume of the matrix [22]. Amin *et al.* [23] analyzed the properties of bioplastics synthesized using 30 mL white vinegar as a solvent and compatibilizer, which showed a maximum tensile strength value of 3.95 N/mm², and elongation reaching 88.1%. It can be concluded that an increase in the volume of vinegar causes a decrease in the tensile strength of a bioplastic. The reason for that case may be that vinegar as a compatibilizer forces the matrix to compact and homogenize thoroughly between the starch and other ingredients [24].

Regarding Young's modulus results, the addition of vinegar tends to decrease, as seen in samples 5 to 6 and 7 to 8. This decrease may be caused by the intermolecular bond between the acetic acid in vinegar and alcohol, including PVA, becoming very flexible. A study by Quilez-Molina *et al.* [25] showed that adding vinegar up to 50% w/w could increase the elongation at break and decrease Young's modulus. This study yielded maximum values for tensile strength, elongation, and Young's modulus of 0.034 N/mm², 225%, and 0.015 N/mm², respectively, obtained by sample 7 with 8 mL vinegar composition.

The increase of PVA as a plasticizer causes an increase in tensile strength. It can be seen that samples 3 and 4 have higher values of tensile strength in comparison with samples 1 and 2. Despite sample 7 having a higher tensile strength value than sample 5, sample 8 has a lower tensile strength value than sample 6. Regarding the elongation, adding PVA as a plasticizer causes increasing in the elongation of bioplastics. The elongation values of sample 3 and sample 4 were higher than sample 1 and sample 2. A similar tendency occurred to sample 7, that higher than in sample 5. Even though sample 8 has a lower value of elongation than sample 6. The Bueno *et al.* [26] study revealed that increasing PVA can increase the value of tensile strength and elongation. This may be because of the bonding between alcohol compounds from PVA and polysaccharide molecules to be solid cross-linkage chains.

Regarding Young's modulus (E) results, adding PVA causes decreasing in elasticity modulus (E). This is caused due to high values of elongation, causing bioplastics to be more flexible. The study by Reshmy *et al.* [7] showed that maximum tensile strength was going to PVA-based bioplastic, which has a value of 193.14 MPa, %elongation at 9.42, and Young's modulus value of 12,836.46 MPa, respectively. For instance, in the study by Mittal *et al.* [27], maximum tensile strength was at 31.21 Mpa, and elongation was at 82.3%, respectively. However, adding PVA as a plasticizer can increase maximum tensile strength to 0.034 N/mm², maximum %elongation of 225, and Young's modulus of 0.015 N/mm², which causes bioplastics to be more tough and flexible.

3.2. Absorption of Water Analysis

Absorption of water analysis was conducted to determine the amount of water uptake due to bioplastics. Reporting to the previous study, adding PVA as a plasticizer caused the decreasing value of absorption of water [7]. On the other hand, PVA also has a hydroxyl group due to its polar characteristic, which means water-soluble because of its interaction with water molecules [28]. The results of the absorption of water analysis can be seen in Table 3. It can be seen that samples 2 to 4, which have the same temperature, occurred a tendency to decrease values of water absorption as well as sample 6 and sample 8. In addition, samples 1 and 3, which have the same temperature, increased the value of water absorption in comparison with samples 5 and 7. These results were almost similar to Azmin and Nor [17] in that bioplastic water uptake was around 23–43% after placing into 20 mL of distilled water for 10 minutes. However, the study revealed that the increase in mixing temperature could decrease water uptake. It was because of the solubility of the polysaccharides used for bioplastic synthesis. In the study by Azmin and Nor [17], cellulose was more unsoluble in water than starch and carbohydrate. Besides the gelatinization temperature increase, vinegar and PVA also contribute to increasing water uptake. This was maybe because acetic acid and alcohol compounds easily form bonds with water molecules. Moreover, adding vinegar as solvent and compatibilizer caused an increase in water uptake because vinegar is water-soluble and hydrophilic [29].

Table 3. Absorption of water results

Sample	Food Vinegar (mL)	PVA (g)	Gelatinization temperature (°C)	Initial weight (g) (W_0)	Final weight (g) (W_1)	Absorption of Water (%)
1	7	8	85	0.388	0.559	44.07
2	7	8	95	0.49	0.642	31.02
3	7	9	85	0.704	1.042	48.01
4	7	9	95	0.502	0.634	26.29
5	8	8	85	0.516	0.687	33.14
6	8	8	95	0.587	0.809	37.81
7	8	9	85	0.795	1.094	37.61
8	8	9	95	0.733	1.009	37.65

3.3. Thermal Analysis

The thermal analysis consists of thermogravimetry differential thermal analysis (TG/DTA). TGA analysis aims to analyze mass and weight loss due to thermal degradation. Meanwhile, DTA analysis aims to analyze the melting points of polymers or materials that involve endothermic and exothermic processes [30]. The temperature was adjusted from 30 to 400°C. Thermal decomposition is presented in Figure 2. The results showed thermal decomposition occurred from under 130°C due to lost light materials such as vinegar, glycerin, and water. Sample 1 was occurring 82.82% of weight loss at 400°C. The 50% weight loss occurred at 180.9°C. Sample 2 had 61.06% of weight loss at 400°C with 50% of weight loss at 230°C. Sample 2 was more thermally stable in comparison with sample 1. In addition, sample 3 experienced degradation of 79.39% at 400°C. These results are similar to sample 4, with a weight loss of 77.21% at 400°C. Sample 5 had a similar result to sample 1, which had 81.89% weight loss. Samples 7 and 8 had similar results, with 74.34% and 72.02% weight loss. These results were almost similar to Mittal *et al.* [27], which observed the thermal stability of starch bioplastics

with PVA as a plasticizer. The result was shown by weight loss of samples around 68.34% and 70.93% during heating at 200–400°C range. Degradation of polysaccharides and volatilization of light compounds and water occurred at this stage. Sample 6 was the most thermally stable, which had 56.36% of weight loss at 400°C.

The thermal properties were also analyzed using DTA. The results of all samples are shown in Figure 3. In this stage, all samples behave almost similar curves, with one peak for exothermic signal and two for endothermic signals. The first exothermic peaks refer to glass transition temperature (T_g), and the first endothermic peaks refer to crystallization temperature (T_c). Also, the second exothermic peaks refer to melting temperature (T_m). All samples behaved because an increase in gelatinization temperature caused the glass transition temperature and melting point to increase. It can be seen that samples 1 to 4 tend to increase due to increasing gelatinization temperature. Sample 2 had the highest glass transition temperature, which was 72.03°C. Sample 1 had the lowest T_g and T_m. All samples had T_g at a range of 60.81–72.03°C. These results were similar to Bueno *et al.* [26], which studied that adding PVA resulted in a T_g of 63.1°C. The highest T_m of 399.97°C was obtained by sample 6, composed of 8 mL of vinegar, 8 g of PVA, and a gelatinization temperature of 95°C. It corresponded with 56.36% of weight loss, which marks the most thermally stable than other samples.

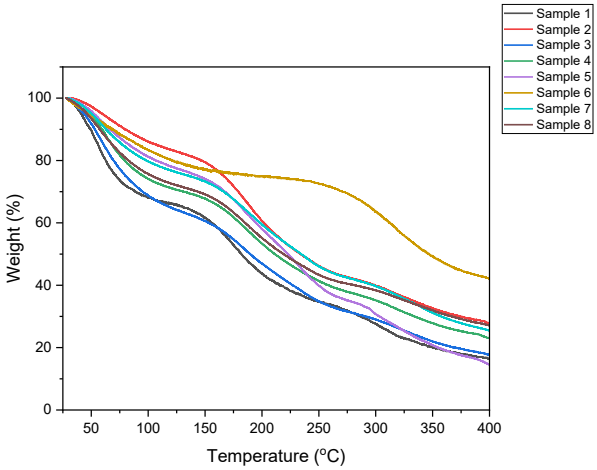

Figure 2. TGA curves of samples

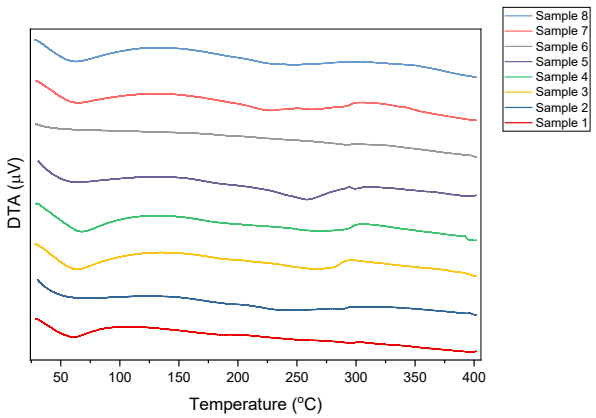

Figure 3. DTA curves of samples

3.4. Functional Groups Analysis

The FTIR spectra analysis showed functional groups of bioplastic samples, as shown in Figure 4. All samples had spectra between 3200 cm^{-1} to 3500 cm^{-1} representing O-H functional group corresponding to polyvinyl alcohol (PVA) content. This was because of the presence of PVA as one of the polyol compounds. The results were similar to Shafqat *et al.* [2], that observed polyols as plasticizers of bioplastic samples and that there were peaks of 3290 cm^{-1} and 3316 cm^{-1}. Another study about O-H functional groups analysis due to the presence of polyols as plasticizers was also noticed by Yaradoddi *et al.* [6], which resulted in a peak of 3352.92 cm^{-1} representing polyol compound. Sample 1 showed an absorption band of 3391.97 cm^{-1}, assigned to an O-H functional group representing polyvinyl alcohol (PVA). This result was nearly similar to Tan *et al.* [16], which observed the presence of PVA spectra at the peak of 3251 cm^{-1}. Then, there were peaks at 2887.56 cm^{-1} and 2942.53 cm^{-1} that represented the absorption band of C-H that corresponded to aldehyde and alkane stretching, which assigned the carbohydrate content of Gambas peel. Other absorption bands exhibited carboxyl groups (C = O), carboxylates groups (COO^-), and C-O groups, which were represented by 1640.53, 1417.74, and 1043.53 cm^{-1} peaks, respectively [26]. Sample 2 showed the absorption band of 3400.65 cm^{-1} that represented PVA spectra. Also, the peak of 2931 cm^{-1} represented the absorption band of the C-H functional group due to the carbohydrate content of Gambas peel.

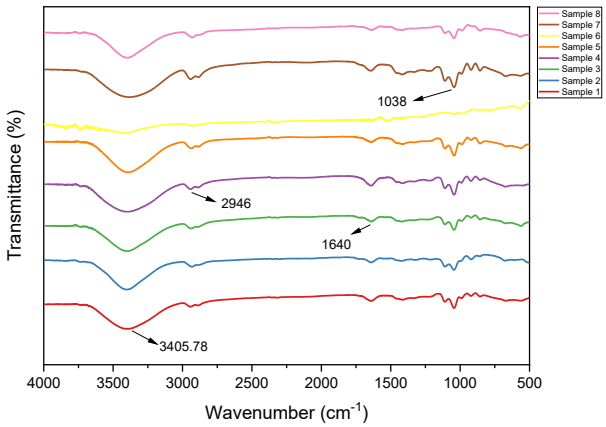

Figure 4. FTIR spectra of bioplastic samples

Samples 3, 4, 5, 6, 7, and 8 also exhibited carbohydrate spectra corresponding to 2937, 2942, 2936, 2926.14, 2940.61, and 2928.07 cm^{-1}, respectively. These results were almost similar to the study by Arafat *et al.* [31], which showed a peak of 2880 cm^{-1} corresponding to a polysaccharide compound. Another observation was also shown by Silva *et al.* [32], which noticed the presence of carbohydrate peak spectra at 2930 cm^{-1}. The spectra of C-H stretching ascribed carbohydrate content were also investigated by Reshmy *et al.* [7], around a peak of 2900 cm^{-1}. The result was similar to the study by Amin *et al.* [23] which observed a peak of 2932.52 cm^{-1} corresponding to the polysaccharide compound. All samples showed small peaks at 1600 cm^{-1} to 1700 cm^{-1} that represented the O-H functional groups of the water compound. According to a study by Huzaisham and Marsi

[33], the peaks around 1590 cm^{-1} to 1720 cm^{-1} ascribed water compound due to O-H of water functional groups.

3.5. Morphological Analysis

The surface morphological images of bioplastic samples were recorded by SEM instrument with magnifications of 500 and 1000 times, as shown in Figure 5. All samples showed the presence of white particles and granules which represented polysaccharide particles. For instance, a study by Mittal *et al.* [27] found that white granules came from starch particles.

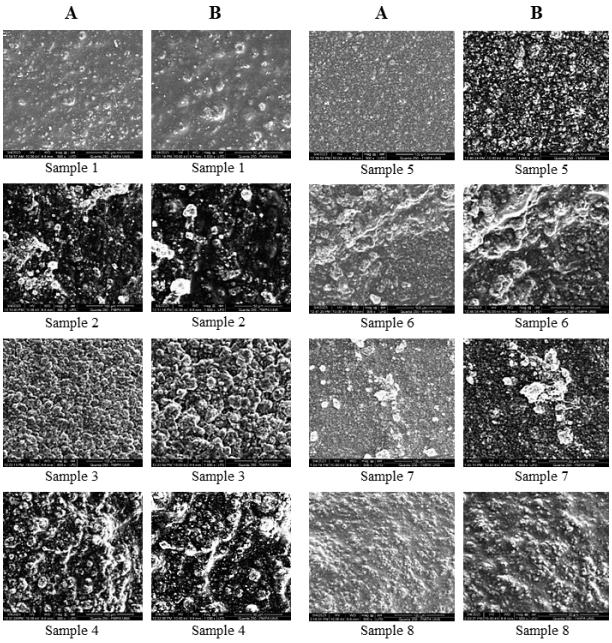

Figure 5. Micrographs of the surface of bioplastics with a magnification of (A) 500 times, (B) 1000 times

Samples 5 and 8 showed uniform dispersion due to the gelatinization process as well in comparison with other samples. Samples 5, 6, 7, and 8 exhibited good morphological dispersion compared to samples 1, 2, 3, and 4. These results were because the increasing volume of vinegar as a compatibilizer made well dispersion between polysaccharide and PVA as an alcohol compound. For instance, compatibilizer was needed to enhance mixture homogenization [24]. It can be seen that samples 5, 6, 7, and 8 had smooth surfaces in morphologies because of good compatibility and had strong intermolecular among compounds that contained bioplastic samples. Adding PVA as a plasticizer enhanced compatibility, good dispersion, and homogenous mixture [34]. In addition, the presence of cracks, voids, and big pores of samples influenced mechanical properties that homogenous surfaces will have good mechanical properties [22].

3.6. Soil Degradation Analysis

Analysis of soil degradation was observed by investigating the results in Figure 6. The initial weight of the sample was weighed before being buried in the soil at room temperature for ten days. After the 5th and 10th days, the samples were weighed to determine the weight due to the degradation process. The results of the soil degradation analysis are available in Table 4. Sample 1 experienced a weight loss of 4.33% after five days and 1.2% after ten days. The weight of sample 2 decreased by 7.8% after five days and 25.62% after ten days. After five days, samples 3, 4, 5, 6, 7, and 8 experienced degradations up to 8.84%, 7.75%, 14.37%, 3.94%, 11.52%, and 19.98%, respectively. Previous studies revealed that vinegar added to bioplastics can be degraded in the soil due to phenolic compounds in vinegar. Thus, the addition of 40 mL of vinegar was able to degrade bioplastic samples for seven days with a weight loss of 14% [35].

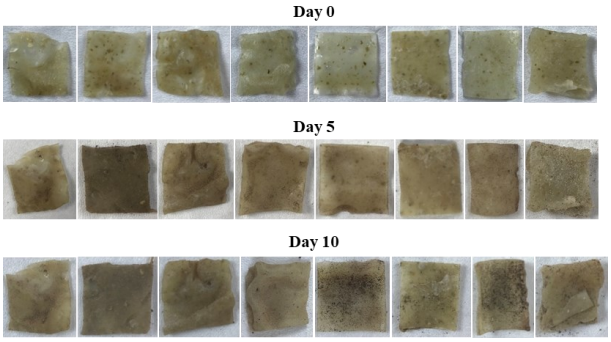

Figure 6. The changes in bioplastic samples during soil burial

Table 4. Soil degradation analysis

Sample	Food Vinegar (ml)	Polyvinyl alcohol (g)	Gelatinization temperature (°C)	Mass of samples (g)			Degradation of Samples (%)	
				Day 0	Day 5	Day 10	Day 5	Day 10
1	7	8	85	0.337	0.323	0.303	4.33	11.2
2	7	8	95	0.608	0.564	0.484	7.8	25.62
3	7	9	85	0.837	0.769	0.763	8.84	9.69
4	7	9	95	0.709	0.658	0.638	7.75	11.13
5	8	8	85	0.533	0.466	0.431	14.37	23.66
6	8	8	95	0.369	0.355	0.349	3.94	5.73
7	8	9	85	0.794	0.712	0.66	11.52	20.3
8	8	9	95	1.663	1.386	1.355	19.98	22.73

PVA added to bioplastic samples has an effect that causes bioplastics to degrade easily in soil. This is supported by previous studies, which revealed that the solubility of PVA has an important role in the easy degradation of bioplastics, so the time required for complete degradation is three weeks [15]. Another study showed that adding 25% w/w PVA could degrade bioplastic samples by about 10% weight loss during a week of soil burial [36]. An increase in gelatinization temperature was reported to increase the degradability of bioplastics in soil which can be seen in Samples 1 to 8. The addition of hydrophilic compounds from plasticizers and compatibilizers also plays an essential role in the high process of degradation of bioplastics in soil [18]. In the current study, the most easily degraded sample (19.98%) after five days was sample 8, with a composition of 8 mL of vinegar and 9 g of PVA. Meanwhile, after ten days, the highest degradation percentage of 25.62% was achieved by sample 2, which contained 7 mL of vinegar and 8 g of PVA.

4. Conclusion

Synthesis of gambas peel bioplastics reinforced by silica using PVA as a plasticizer and vinegar as a compatibilizer was successfully investigated. Adding PVA and vinegar was increasing mechanical properties. Sample 7 had a tensile strength of 0.034 N/mm^2, a maximum %elongation of 225, and Young's modulus reached 0.015 N/mm^2. In addition, sample 6 had better thermal stability than other samples, which had 56.31% weight loss by heating up to 400°C and melting temperature of 399.97°C. Although the bioplastic samples were less waterproof, adding vinegar as a compatibilizer revealed a homogenous mixture in surface morphological analysis. FTIR spectra revealed that samples did not react because of containing constituent materials. However, hydrophilic conditions may increase bioplastic sample mass. Due to the soil degradation test, sample 2 had the highest weight loss reached at 25.6% after ten days of soil burial. However, the best performance of bioplastic was obtained by sample 7 with the composition of vinegar of 8 mL, PVA of 9 g, and gelatinization temperature of 85°C. The results showed that the maximum tensile strength reached 0.034 N/mm^2, the elongation was 225%, the value of Young's modulus was 0.015 N/mm^2, the thermal stability reached 74.34 % weight loss by heating up to 400°C, and the melting temperature reached 220°C, the absorption of water was 37.61%. The weight loss was 20.3% during ten days of soil burial.

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